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A model for incrementally transforming the science classroom from traditional instruction to inquiry

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A MODEL FOR INCREMENTALLY TRANSFORMING THE SCIENCE CLASSROOM FROM TRADITIONAL INSTRUCTION TO INQUIRY

A Project

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ABSTRACT

This project explores the research regarding direct instruction and inquiry. The traditional direct instruction methodology of science teaching is based upon the behavioralist philosophy of learning. This philosophy still prevails in the science classroom even though, research regarding how people learn support the constructivist philosophy of education. It is widely supported by experts in the field of science education that inquiry-based instruction gives students an improved opportunity to learn science. In this project I explore the implementation of inquiry into the science classroom. I have created a model for incrementally changing the traditional instruction found in the science classroom to inquiry-based instructional strategies. There is research still to be done into the use of STS (science, technology and society) into inquiry-based lessons to improve science achievement further.

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CHAPTER ONE

INTRODUCTION TO SCIENCE EDUCATION REFORMS

On October 5, 1957 Russia launched the satellite, Sputnik into orbit around the Earth. This advancement into space by the Russians released a wave of concern regarding science education programs in the United States. Striving for domination over Russia in the space race drove the U.S. to reform science education and to implement new programs during the late 50's and 60's (Rutherford, 1997). Critics of science education in the pre-Sputnik era claimed that science content "was often presented in isolated bits and pieces of information to be memorized without developing a sense of the relationships between broader ideas" (Rhoton, 2001). The National Science Foundation had "expressed growing concern about the shortage of high school students entering scientific fields" (Dow, 1997) in 1955 before Sputnik was even launched. It was not until the competition between the U.S. and Soviet Union to put the first man on the moon began, that the federal government took action to improve science education in the U.S.

Congress acted quickly approving the National Defense Education Act of 1958 giving federal funds to improving science education and encouraging students to choose scientific fields when entering college (Lederman, 2006). The U.S. federal government devoted millions of dollars to science education reform during the late 50's and 60's. The programs of the 1960's "combined strong science content, a view of science as inquiry, and innovative instructional approaches" (Rhoton, 2001). The curriculum reformers of the 1960's used the word "inquiry" equal to the term "discovery." In the 1960's inquiry was described as a set of skills that could be "learned independently of the science content" (DeBoer, 1997). The curricular shift after Sputnik was

> based on conceptually fundamental ideas and modes of scientific inquiry and mathematical problem solving. The reform would replace textbooks with instructional materials that included films, activities and readings. No longer would schools' science and mathematics programs emphasize information, terms, and applied aspects of content. Rather, students would learn the structures and procedures of science and mathematics disciplines. (Bybee, 1997)

A positive implication of the post-Sputnik era was the development of many science education programs including the Physical Science Study Committee (PSSC), the Chemical Education Materials Study (Chem study), the Biological Sciences Curriculum Study (BSCS) and the Earth Science Curriculum Project (ESCP) (Bybee, 1997). The problem with these science education reforms was that teachers were not given adequate tools and training to implement the new programs properly. "The educational innovators of the 1960s found themselves in the hands of hostile and unreceptive publishers who had not participated in the enterprise" (Dow, 1997). Along with the lack of teacher training, Neil Armstrong walked on the moon, causing the importance of science education as a national concern in the U.S. to diminish. The federal funding of reform programs began to be cut just as they were beginning to take hold within the science classroom. It seemed that after the U.S. took its place at the top, after the scientific breakthrough of putting a man on the moon "a relaxed nation began to turn to other concerns, to lose its focus on producing a "scientific priesthood" and a scientifically competent citizenry" (Fox, 1997). The Vietnam War protesters during this time period in the 1970s "disdained the deferred gratification that comes with in-depth study of difficult subjects; they attacked the notion of required, core courses: and they encouraged the flowering of electives that were sometimes light in content. Standards began to slip, and grades to inflate" (Fox, 1997). As a result of the late 1970's governmental lack of concern over science education the quality of science education began to slip.

"In 1983, *A Nation at Risk* was published, calling for a reconsideration and reform of the U.S. education system" (NRC, 1996). During the 80's, once again, organizations such as the American Chemical Society (ACS), the BSCS, the Education Development Center (EDC), and the National Science Resources Center (NSRC) worked to developed new science curricula based on educational research. The American Association for the Advancement of Science (AAAS) published *Science for All Americans.* Due to the increased awareness in the need for science education reform the National Science Teachers' Association (NSTA) asked the National Research Council (NRC) to coordinate the development of the National Science Education Standards (NSES) along with the cooperation of the NSTA, AAAS, ACS, NSRC, and many other education groups. The funding for this project was provided by the Department of Education and the National Science Foundation (NSF). The National

Science Education standards first draft was distributed for comment by all interested science stakeholders in 1994. It was revised based on carefully catalogued and implemented feedback data and then re-published to its current form in 1996. The pendulum in science education began to swing from the didactic direct instruction approach pre-Sputnik to more emphasis on inquiry post-Sputnik. Due to a lack of following through with teacher training inquiry during this time inquiry was often confused with discovery learning. In the late 1980's, 1990s' when science education was being reformed again and the NSES were developed, inquiry was included in the discussion. With the pressures of NCLB and the stresses of "covering" a vast amount of material, teachers seem to be holding onto direct instruction methods only, for teaching science.

Throughout this report, take notice that the term discovery is not the same as inquiry. Discovery learning is when the students figure out all of the information on their own. The students work on their own to discover the basic principles. This type of learning differs from inquiry because there is no structure or guidance from the teacher during discovery learning. In the current definition of an inquiry-based lesson plan "the teacher organizes the class so that the students learn through their own active involvement" (Woolfolk, 2001, p. 285).

"Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of how scientists study the natural world" (NRC, 1996, p. 23). The term scientific inquiry is used in many ways. Throughout this project I will use the term inquiry to describe the activities used in the science classroom along with the skills being developed while using these lessons. "Inquiry means asking questions and attempting to answer them through various means of investigation. Inquiry is carried out on researchable questions of genuine interest to students in the context of the content being studied at the time" (DeBoer, 1997).

Learning science is not only learning the facts about a natural occurrence, it is also learning how science is performed. According to the *National Science Education Standards* science is an active process and involves physical manipulations as well as cognitive activity. "Hands-on activities are not enough-students also must have "minds-on" experiences. Science teaching must involve students in inquiry-oriented investigations in which they interact with their teachers and peers" (NRC, 1996, p. 20). The National Science Education Teaching Standard A states "Teachers of science plan an inquiry-based science program for their students" (NRC, 1996, p. 30). At the 9-12 grade level students are expected to develop understandings of scientific inquiry and the abilities necessary to do scientific inquiry. According to Roger Bybee (2002) inquiry is a set of cognitive abilities that students should develop so that, science content can be understood and as teaching methods that science teachers can use. The curriculum studies for the past 40 years in science education have supported the use of inquiry in the classroom, however most science teachers do not have an inquiry-based classroom. This discrepancy between current practices and what works has lead me to investigate the primary instructional methodologies used in science education and their effect on achievement in science.

A highly used instruction method used to teach science is direct instruction. "Direct Instruction is based on Engelmann's theory that children learn at an accelerated rate if educators deliver instructions that are clear, are able to predict likely misinterpretations and therefore reduce confusion, and assist informing generalizations" (ADI, 2003). Strategies within the direct instruction teaching method include scripted lessons, rapid-paced interaction with students, correcting mistakes immediately, achievement-based grouping and frequent assessments. The lessons taught using direct instruction are highly structured and teachers present material to students in an overt way, instead of allowing students to develop accurate conclusions based on their own understandings. Researchers at Carnegie Mellon University and the University of Pittsburgh conducted a study regarding the achievement of students that were taught with the direct instruction method. The study found that these students were more likely on average to become "experts" in designing scientific experiments than those who were taught through the process of discovery learning (Cavanagh, 2004).

"Rowena S. Douglas, the NSTA's assistant executive director for professional development, estimates that a strong majority of science teachers nationwide rely heavily on textbooks to guide lessons, supplementing with lectures and laboratory work- an approach that qualifies as a form of direct instruction" (Cavanagh, 2004). Not all forms of direct instruction are completely scripted. The degree to which lessons are lead by the teacher when using direct instruction varies from having completely passive learners to students being engaged with the teachers' explanation or laboratory activities with a clear procedure. The students taught through direct instruction do not explore the topic, they are given the information by the instructor.

Within the science classroom teachers need to recognize and implement teaching techniques that will increase student learning and build a population of citizens with scientific literacy. There are several different strategies that can be employed to achieve this goal. In the current environment of high stakes science content assessment it is tempting for many science educators to "teach to the test" using didactic methods and deny students the opportunity for deep conceptual understanding of science. Teachers often feel that there is not enough time to "cover" material adequately and to allow students time to think and explore the information. Teachers also often feel that the direct instruction teaching method is effective for disseminating information to students (Cavanagh, 2004). This suggests that with the pressures of No Child Left Behind and state content standards teachers may feel that direct instruction is a more effective teaching method to employ then inquiry based instruction. Science educators need to know that it is possible to have a rigorous content-based curriculum and teach students the skills they need to become scientifically literate. Creating an inquiry-based environment will engage students in learning as they are taught the subject matter through active participation with the science information. Experiences that foster learning can be given to students when the science classroom is transformed from the teacher-centered, traditional direct instruction based methodology to a student-centered, inquiry-based atmosphere. Bransford, Brown, and Cocking (2000) in *How People Learn* describe the implications of cognitive research on science education. Their research into cognitive learning process supports inquiry-based teaching of science courses. Their findings include the importance of prior knowledge and overcoming misconceptions as a bridge to new knowledge, the role of metacognition, and the role of inquiry to develop understanding. Yet, direct instruction prevails in U.S. classrooms.

Conclusion

Throughout this chapter I have described the evolution of science education over the last fifty years.

Reforms have often been caused by the competition between the United States and other countries. Most of the reforms that have been put in place have not had long-term support or did not have adequate teacher training leading to the demise of reform program. As the scientific community comes to conclusions about how people learn science educators are using this information to instruct students. The question that should be on the minds of science educators is, what is the best way to educate students of science? How do we implement these methodologies into science classrooms? I believe that it begins with a clear understanding of inquiry and direct instruction. Teachers need to know about the philosophies of education that lead to these instructional strategies. They also need to be aware of the research surrounding these methods as well as the research regarding how students learn science.

CHAPTER TWO

REVIEW OF THE LITERATURE REGARDING INQUIRY AND DIRECT INSTRUCTION

Bransford, Brown, and Cocking (2000) made three key findings in their influential book *How People Learn* (HPL). These findings have had a profound effect on how science is taught as one looks at how students learn. "Students come to the classroom with preconceptions about how the world works. If their initial understanding in not engaged they may fail to grasp the new concepts and information they are taught." The traditional philosophies of behaviorism disagree with these findings describing students as empty vessels ready to be filled with knowledge. The HPL findings do, however, coincide with the constructivist point of view that students construct knowledge using their experience. Teachers must engage students into thinking by creating tasks in which students' thinking can be exposed. Often, even after a correction of a misconception students will hold fast to their previous belief. "For the scientific understanding to replace the naïve understanding, students must reveal the latter and have the opportunity to see where is falls short" (Branford et al., 2000, p. 14). Overcoming of misconceptions can be accomplished through inquiry-based lessons as students first access their prior knowledge during the engagement into the topic. They then explore a concept and explain their conclusions. If the conclusions do not match with the previous understanding the student may have an opportunity for changing their thinking. Without the activation of prior knowledge and exploration of the topic the learner would not recognize the relationship between the new information and the preconceived notions.

Another key finding was that for students to "develop competence in an area of inquiry, students must (a) have a deep foundation of factual knowledge, (b) understand facts and ideas in the context of a conceptual framework, and (c) organize knowledge in ways that facilitate retrieval and application" (Bransford et al., 2000, p. 16). When one understands the subject matter in a deep way they are able to transform the factual information into useable information.

Bransford, Brown, and Cocking (2000) also found that "A metacognitive approach to instruction can help students learn to take control of their own learning by defining learning goals and monitoring progress in achieving them" (Bransford et. al, 2000, p. 18). During the evaluation phase of the 5E inquiry lesson model students can challenge their own thinking by evaluating their own progress toward a particular learning objective. These findings are applicable to the teaching of science.

Science is the body of knowledge that is obtained through scientific research. Science is also a system of acquiring knowledge through observation and experimentation that can be replicated aimed at finding how the natural world works both now, in the past and in predicting the future. Often students and teachers believe that science is only the facts, theories, laws, definitions, and relationships described in science textbooks. Science is not just the body of knowledge that stays the same across time. The knowledge can change and grow throughout history as new discoveries are made and new technologies are used to process information. Previously accepted ideas are changed with the input of new data. Science is a way of thinking about the natural world. "The results of science are inseparably intertwined with its thought processes; both together are needed to understand what science is" (Derry, 1999, p. 4). The complex integration of process skills and scientific knowledge challenges teachers of science to convey both aspects of the discipline to students.

The route to scientific discoveries is diverse. A misconception held by most people including science teachers is that scientific discovery is consistently systematic in its development. The scientific method is taught in most science classes as a precise, rigid, and impersonal process when in reality the arrival of scientists to discoveries is often the opposite (Bybee, 2002, p. 27). According to Derry scientific breakthroughs are made in a variety of ways from serendipity to observation and experimentation to the creation of new technology as a pathway to new knowledge. Sometimes discrepancies lead to discoveries. Derry (1999) and Kuhn (1996) describe that most science is not groundbreaking and leading to new discoveries. Science mostly is making the already known information more concise. Kuhn refers to this as normal science. These views about the nature of science are vastly different then how science is taught in most classrooms. For students to develop science skills they must engage in inquiry activities that stimulate the mind to think critically about topics within science. Students of science are often not taught in a way that encourages the use of the science process as it is used by scientists. They are given cookie cutter lab activities with no opportunity for complex thinking to occur. Given the knowledge about how people learn, one could alter the current methods of didactic teaching to inquiry-based instruction.

Science is a subject that cannot be taught in the same way that English or History is taught in school. When learning about topics in science one not only learns the specific factual knowledge but also the process of gaining scientific knowledge. In society people need to be able to analyze information and come to conclusions based upon evidence. Students of science need to become critical thinkers in a different way then analyzing a math problem.

> Different disciplines are organized differently and have different approaches to inquiry. For example, the evidence needed to support a set of historical claims is different from the evidence needed to prove a mathematical conjecture, and both of these are different from the evidence needed to test a scientific theory. (Bransford, Brown, & Cocking, 1999, p. 143)

Based upon the expectations of science learning students need to be taught science in a different way than other disciplines that are taught in school. The demands on students of science are not only to understand the scientific body of knowledge but also to become analytical thinkers. Not only do they need to know, they also need to be able to do.

According to the Program for International Student Assessment (PISA) students in the U.S. are outperformed by many other countries in the subject of scientific literacy (Bybee, 2005). The PISA is given by the Organization for Economic Co-operation and Development (OECD) which is comprised of 30 industrialized countries. The subjects that the PISA assesses are reading literacy, science literacy, and mathematics literacy. "Literacy of science is defined as the capacity to use scientific knowledge, to identify questions and to draw evidence-based conclusions in order to understand and help make decisions about the natural world and the change made to it through human activity" (OECD, 2006). Each subject is measured in detail every three years while the other two subjects are measured but not with the same depth. In 2003 mathematics was the primary subject measured and in 2006 science will be the primary subject. Although science literacy was not the focus of the assessment in 2003, useful data was attained. Upon completion and analysis of the results regarding science literacy measured by the 2003 PISA "the United States average was measurably below the OECD average" (Bybee, Kilpatrick, Lindquist, & Powell, 2005, p. 5).

The PISA measures application of science knowledge. This assessment "focuses on young people's ability to use their knowledge and apply their skills to real-life situations" (Bybee, 2005, p. 16). Students in the United States are lacking in the skills to use the knowledge they have gained to solve problems. They have difficulty reaching conclusions based upon evidence. Students can often recall information but are not able to utilize the information to resolve problems. The goal of inquiry-based teaching methods is to help students understand the content knowledge while they learn how to use the knowledge. The results of the PISA suggest that educators in the U.S. are not utilizing inquiry based methodologies. An alternative hypothesis suggested by Schmidt (2005) is that the U.S. curriculum is a "mile wide and an inch deep." It seems that other countries may have "a more focused and challenging curriculum" (2005, p. 18).

The Trends in International Mathematics and Science Study (TIMSS) was recently completed by students in the United States during 2003 to assess science content knowledge. It was funded by the U.S. Department of Education, the National Science Foundation (NSF), the

World Bank, the United Nations Development project, and the participating countries. This assessment measures student achievement in science and mathematics in the fourth and eighth grade. TIMSS measures the "degree to which students have learned concepts in science and mathematics they have had the opportunity to learn in school programs" (Bybee et al., 2005, p. 8). It measures what the students have been taught within the participating country. In 2003, U.S. fourth-graders exceeded the international average in the TIMSS science assessment. However, U.S. fourth graders' average score decreased between 1995 and 2003 (Bybee et al., 2005, p. 9). Unfortunately science education has not advanced our population of students to a higher level of achievement than has been previously attained. Eighth grade students are not doing consistently well in all disciplines. They perform very well in some disciplines and poorly in others (Bybee et al., 2005). The TIMSS report suggests that science education is currently taught in a way that fosters only the factual knowledge of the science content, at best.

The results of the TIMSS report and the PISA imply that science education in the U.S. is producing students that have science content knowledge in some science subject areas, according to the TIMSS, but do not know how to apply this information, according to the PISA. The use of direct instruction method for teaching science may be the cause of the discrepancy between the TIMSS and PISA results because the students are taught the information only, they can not apply the information. These assessments should be an indicator for science educators to refocus their efforts on students' ability to solve real-world problems while learning about the specific science content. A possible reason for the decrease in the number of students choosing careers in science and engineering could be the lack of connection between science content and its application.

> In 1966, U.S.-born males received 71 percent of science and engineering PhDs, U.S.-born females earned 6 percent of those degrees, and foreign-born students received 23 percent of those doctorates. By the year 2000, U.S.-born white males received just 35 percent of science and engineering PhDs, while 25 percent of those doctorates were awarded to females and 39 percent to foreign-born students. (Francis, 2006)

Although the reason for this trend is due to economic advantages in other educational pursuits these science and engineering PhD graduates are significant to the national technological advancement. The importance of science as a career needs to increase if the United States wants to continue as an economic power in the world market. Students need to feel that science has important applications in their lives and is a necessary venture if they are going to choose science as a career goal. The way to enhance the quality of scientific work in the United States is through premium science education for all students.

Direct Instruction

There are many different teaching strategies that are utilized by science educators to instruct students. One of the approaches used is direct instruction. Direct instruction is a teaching strategy that is utilized by many science educators and is based upon the ideas of instructivism. Instructivism is characterized by the transmission method which traces the flow of information from the teacher to the learner. The traditional lecture where the teacher talks and the students listen is an example of instructivism. This concept was born out of the philosophy of behaviorism. Behaviorism roots can be traced back to the early 1900's from the finding of Pavlov, Watson and Skinner. Behaviorism claims that the only reality is the physical world that humans interpret through observation. People respond to external stimuli. This concept focuses on a new behavioral pattern being repeated until it becomes automatic. "It views the mind as a "black box" in the sense that response to stimulus can be observed quantitatively, totally ignoring the thought process occurring in the mind" (Mergel, 1998). The brain responds to stimuli, therefore learning is merely an act of memorization of the response to such stimuli.

Behaviorism has a significant impact on the instruction of students. According to Skinner:

> The application of operant conditioning to education is simple and direct. Teaching is the arrangement of contingencies of reinforcement under which students learn. They learn without teaching in their natural environments, but teachers arrange special contingencies which expedite learning, hastening the appearance of behavior which would otherwise be acquired slowly or making sure of the appearance of

behavior which otherwise would never occur. (Skinner, 1968, p. 64)

Knowledge, according to a behavioral approach, is a matter of remembering rather then acquiring the information. The understanding of the information on the part of the learner would be recognition of patterns among the information.

Behavioral learning does not usually demand that the learner be able to put the skills or knowledge to use in a real world situation. It may be assumed by this approach that the learner will be able to perform the task because they have the knowledge needed. For example one may be given the information about how to perform a task such as changing a tire. It is then assumed that because they have information, they can complete the activity. Each stimulus has a correct response. After repetition of the response with the stimuli, the response becomes automatic and learning occurs according the behaviorist model. An analogy to an educational setting would be that each question asked has a specific answer, therefore if one were to repeat a question with the correct answer the learner would eventually give the appropriate answer to the question routinely. For example, when reviewing the base-pairing rules of DNA adenine pair with thymine a teacher using this model would probably have the students repeating adenine with thymine until students have the information memorized.

Direct instruction is an approach that assumes there is the existence of an external body of knowledge which may be transferred to the learner via the instructor. The knowledge is in possession of the teacher. The material is delivered by the teacher. The students then acquire the information given by the teacher. Students are then assessed on their ability to remember the information as they respond to the stimuli, the question. In an instructivist classroom the flow of information is one way, from the teacher to the students. The students are simply passive receivers of knowledge. Learning is a stimulus-response association that shapes desirable behaviors toward as specific goal (Fardouly, 1998). "Rather than inventing solutions and constructing knowledge in the process students are taught how to "get the right answer" using the teacher's method. Students do not even have to make sense of the method to solve the problem" (Qureshi, 2001).

During direct instruction the learning objective can range from memorization to analysis and synthesis of information. One example of a lesson outline using direct instruction was developed by Madeline Hunter. During this type of lesson the teacher begins by defining the objectives that are to be met by the students at the end of the lesson. One must then identify the specific standards that are to be addressed during the lesson. The students should be informed of these objectives and the standards of performance to which they will be measured.

The teacher then engages the learner through an anticipatory set. This focuses the learners' attention to the lesson. The teaching of the lesson then begins with input from the teacher via lecture, videos, or pictures. The teacher then models the expectation for the outcome of their work. They students may then be asked to label or categorize information. They can also be taken to the application level through defined problem-solving approaches, comparison and summarizing.

The teacher then checks the students for understanding. This involves the teacher determining whether the students have an understanding of the material before proceeding. When using direct instruction the teacher must assess if the students are doing it correctly before moving to the next step. If there is doubt that the class lacks understanding the concept should be re-taught before practice begins. Guided practice allows an opportunity for each student to demonstrate the new knowledge by working through an activity or exercise under the teacher's direct supervision. The teacher moves around to determine the level of mastery and to provide remediation.

The subsequent part of the lesson is closure. The statements by the teacher are designed to bring the learner to an appropriate conclusion. It brings the information together in the mind of the students. They are able to then make sense of what they have been taught as it helps to organize student learning, to eliminate confusion and frustration, to reinforce major points to be learned. Closure also helps to establish the network of thought relationships that provide the cues for retrieval of information. The stimuli and response are made clear for future need for the correct response. This ensures the students' ability for application.

The final stage of a direct instruction lesson is independent practice. It is a repeating of the information so that it is not forgotten. It may be homework, group work, or individual. It should involve a varying context so that the concept can be applied to a relevant situation. Failure to complete the final stage results in students' inability to apply the information they learned during the lesson (Allen, 1998). The concept of the direct instruction lesson as presented is that the students are given the information by the teacher, practice the concept with the teachers control, clarification by the teacher of the students learning outcomes, and application by the student of the concept they learned. One can see the correlation between this lesson and the practice of stimuli and response used by Skinner.

The effectiveness of direct instruction can be analyzed by the achievement of students that are taught using direct instruction. Klahr and Chen explored the effectiveness of using direct instruction by working with elementary students and their ability to obtain the Control of Variables Strategy (CVS). CVS is a method for creating experiments in which a single contrast is made between experimental conditions. The

> explicit training within domains, combined with probes, proved to be effective in facilitating the acquisition of CVS. Receiving direct instruction concerning CVS not only improved the use of CVS but also facilitated conceptual change in the domain because the application of CVS led to unconfounded, informative tests of domain specific concepts. (Chen & Klahr, 1997)

This study supports direct instruction as a strategy to teach science concepts as the students achieved at higher-level then students that were taught using the discovery method without teacher instruction. Klahr's controlled studies continue to demonstrate that, at least for many of the multistep procedures in science, direct instruction works and generalizes better (then discovery methods) (Adelson, 2004). Recall that discovery methods are different from inquiry-based teaching, although many people do not make the distinction. Due to the lack of clarification between the two terms people infer that a comparison of direct instruction with discovery would yield the same results as a comparison of direct instruction with inquiry.

Klahr and Nigam conducted another study with third and fourth grade students measuring the effectiveness of direct instruction as compared to discovery learning at two points in the learning process. They measured achievement during the initial acquisition of a procedure for designing and interpreting simple, unconfounded experiments and during the application of this basic skill to the evaluation of science fair posters. They found that many more children learned from direct instruction than from discovery learning. Also that when asked to make broader, richer scientific judgments the children who learned about experimental design from direct instruction performed as well as those children who discovered the method on their own. "These results challenge predictions derived from the presumed superiority of discovery approaches to teaching young children basic procedures for early scientific investigations" (Klahr & Nigam). Again the confusion of discovery with the current definition of inquiry leads to a misconception of direct instruction being superior, when in fact the two methodologies have not been compared.

Project Follow Through was the largest, most expensive educational experiment ever conducted. In the 1970's over 75,000 low-income children in 170 communities were involved in this massive project designed to evaluate different approaches to educating economically disadvantaged students from kindergarten through grade 3. Each participating district implemented the selected sponsor's approach in one or more schools. The most effective teaching program was Direct Instruction which contains many components of the direct instruction teaching methodology. The results of this study found that the use of the Direct Instruction program out performed all other programs in the achievement of reading, math, spelling, and language (AID, 2003).

In the implementation of this program the children are seated individually facing the teacher. "The teacher has a blackboard, overhead projector, or other visual aids that are used to present stimuli to the learners. The teacher periodically refers to a script that contains carefully sequenced instruction, questions and prompts. These scripts have been field tested with other learners and have been designed to maximize learning and minimize confusion" (Kinder & Carnine, 1991). The easily accessible prepared lessons allows the teacher to focus on motivational and extra-instructional features of the learning environment. The instruction is fast-paced as the children respond in chorus to questions asked by the teacher.

The students taught with this method during Project Follow Through, made educationally significant gains when their test scores were compared to students' in the other Follow Through models. These initial effects endured with fifth-and sixth-graders maintaining their academic advantages and high-school students not only maintaining academic advantages but also achieving higher college acceptance rates than comparison groups (Carnine & Kinder, 1991). The problem with this study as it relates to science education is that science was not one of the curricular areas in which achievement was measured and analyzed. One may infer that due to the significant increase in other areas there may have also been an increase in science achievement. The supporters of direct instruction would make this assumption. The fact that science was not tested may be because it is not effective for science teaching. Another important point is that these comparison programs were not inquiry-based, they were discovery based as in the previous study that was described.

While direct instruction seems to have a place with the teaching of language arts and mathematics there is little research to suggest the direct instruction alone is an effective methodology for teaching science yet it is widely used. "The essence of direct instruction is to help the student acquire broad factual knowledge to enhance basic cognitive and communication process skills. This method of instruction is useful in filling students' knowledge gaps that may hinder inquiry-based science instruction" (Farenga, Joyce, & Ness, 2002).

Inquiry-Based Instruction

The use of inquiry to teach science is recognized by National Science Teacher's Association (NSTA), American Association for the Advancement of Science (AAAS), National Research Council (NRC), American Chemical Society (ACS) and many other science education related organizations. "A prerequisite for becoming an inquiry-based teacher is embracing a philosophical mind-set founded on the ideals and principles of constructivism" (Llewellyn, 2005). Constructivism is a philosophy of learning founded on the premise that humans construct their own understanding of the world. The learner must actively build knowledge and skills. Constructivism values developmentally appropriate, teacher-supported learning that is initiated and directed by the student (Wikipedia, 2006).

The theoretical base of constructivism as a mechanism for learning was articulated by Jean Piaget, John Dewey, and Lev Vygotsky. According to Llewellyn (2005, p. 32) "Dewey believed that learning and experience go hand and hand and that knowledge emerges from a personal interaction between the learner and their external environment. He felt that posing problems of significant interest that draw upon the students' prior knowledge activates the learning process." His ideas have had a profound effect on environmental and outdoor education due to the interest and use of a "hands-on" approach. The providing of problems for students to solve aligns with the intent of inquiry-based instruction.

Piaget was the first of the psychologists to shift the focus of learning from behavioral to cognitive. He suggested that through the process of accommodation and assimilation individuals construct new knowledge from their experiences. "They (students) assimilate the new experience into an already existing framework. Accommodation is the process of reframing one's mental representation of the external world to fit new experiences" (Wikipedia, 2006). The process of failure leads to learning. When individuals act on there expectations of the world and it violates a pre-existing notion, the new experience reframes the existing perspective and they learn from the integration of new information. He had four key principles to his learning theory. People develop though stages of cognitive growth. Knowledge is a result of ever-changing social interactions between the individual and the environment. Knowledge is constantly being constructed and reconstructed from previous and new experiences. Cognition is self-regulating within the individual and the interaction with the physical and social environment (Llewellyn, 2005, p. 36).

As described by Llewellyn (2005) Vygotsky added to the philosophy of constructivism by focusing on the influence of language and social processes of cognitive development. In his view construction of knowledge is socially mediated. An "important factor in social learning was a young person's ability to learn by imitating and modeling. Interacting with adults and peers in cooperative settings gave young children ample opportunity to observe, imitate and model" (Vygotsky, 1978, pp. 79-80).

In contrast to behaviorism, constructivists do not believe that students are blank slates or empty vessels with which teachers can dispense information into the student's head. Constructive learning is based upon cognate, not behavioral, processes. Constructivism describes how learning occurs. According to the National Research Council (2000, p. 14)

> students come into the classroom with preconceptions about how the world works. If their initial understanding is not engaged, they may fail to grasp the new concepts and information that are taught, or may learn for

the purpose of a test but revert back to their preconceptions outside the classroom.

Educators have pedagogies that are based upon the philosophies of constructivism. Constructivists lead students through inquiry and investigation allowing the learner to construct their own knowledge about the concept. Most approaches that have grown from constructivism suggest that learning is accomplished best using a hands-on approach. Learners learn by experimentation, and not by being told what will happen. They are left to make their own inferences, discoveries and conclusions. Students learn the new information that is presented to them by building upon knowledge that they already possess. It is therefore important that teachers constantly assess the knowledge their students have gained to make sure that the students perceptions of the new knowledge are what the teacher had intended. Teachers will find that since the students build upon already existing knowledge, when they are called upon to retrieve the new information, they may make errors (Matthews, 2000). The teacher's role in a constructivist classroom is not only to observe and assess but also to engage with the students while they are completing activities and posing questions. Teachers also intervene when conflicts arise but they simply facilitate the students' resolutions to the problem. They must attempt to figure it out for themselves.

The constructivist view of the classroom differs from the traditional classroom as shown by the following comparison supplied by Brooks and Brooks (1999):

Table 1. Comparison of A Traditional Classroom to A Constructivist Classroom

Traditional Classrooms	Constructivist Classroom
Curriculum is presented part to whole with emphasis on basic skills.	Curriculum is presented whole to part with emphasis on big concepts.
Strict adherence to fixed curriculum is highly valued.	Pursuit of students' questions is highly valued.
Curricula activities rely heavily on textbooks and workbooks.	Curricula activities rely heavily on primary sources of data and manipulative materials.
Students are viewed as blank slates onto which information is etched by the teacher.	Students are viewed as thinkers with engaging theories about the world.
The teacher generally behaves in a didactic manner, disseminating information to students.	The teacher generally behaves in an interactive manner, mediating the environment for students.
The teacher seeks the correct answer to validate student learning.	The teacher seeks the student' points of view to understand students' present conceptions for use in subsequent lessons.
Assessment of student learning is viewed as separate from teaching and occurs almost entirely through testing	Assessment of students' learning is interwoven with teaching and occurs through teacher observations of students at work and through student exhibitions and portfolios.
Students primarily work alone.	Students primarily work in groups.

(Brooks & Brooks, 1999)

In the constructivist classroom the learning revolves around the actions of the student not those of the teacher as in a traditional setting. Students work to develop their own understanding of the material instead of passively allowing the teacher to provide the information. Constructivism, along with metacognition, provide the basis for an inquiry based science education setting. Metacognition is an awareness and regulation of one's own learning process. The responsibility of learning falls on the student as they analyze their own thinking and learning. Developing the culture of inquiry allows the students to engage in reasoning, decision-making and reflection.

Students who engage in inquiry learn science, learn the nature of science, and learn science content simultaneously. "Investigations can be highly structured by the teacher so that students can proceed toward known outcomes such as discovering regularities. Or investigations can be free-ranging explorations of unexplained phenomena" (NRC, 2000, p. 10). There is a wide variety of teacher involvement within inquiry lessons. There is a continuum from teacher centered to student centered inquiry lessons. Inquiry is not merely "discovery" where the child explores the topic with no time or resource restraint. Trowbridge and Bybee (1990) discuss three levels of inquiry. The least most student-centered level is called discovery learning, in which the teacher sets up the problem and processes but allows the students to identify alternative outcomes. The next level of complexity is guided inquiry, in which the teacher poses the problem and the students determine both processes and solutions. The third level is called open inquiry, in which the teacher provides the context for solving problems that students then identify and solve with teacher coaching and clarification.

The vision of inquiry-based instruction is to create an environment where students are engaged with scientific problems and the teacher helps to guide their learning toward the educational objective. It is also important to note that there are numerous teaching strategies that can be effective for student learning. Inquiry is one of the most important teaching strategies in science and a skill that needs to be developed for students to achieve science literacy. Inquiry-oriented instruction can mean teaching about the nature of science or that students learn science concepts by using the processes of scientific inquiry. In this analysis of inquiry I am focusing on students learning concepts through the process of inquiry.

"The natural inquiry of children and the more formal problem-solving of adults often follow a pattern of initial engagement, exploration of alternatives, formation of an explanation, use of the explanation, and evaluation of the explanation based on its efficacy and responses from others" (Bybee, 2002, p. 31). This parallels the progression of scientific inquiry. The Biological Science Curriculum Study (BSCS) provides an excellent summary of an inquiry-based instruction plan. The 5-E model presented by the BSCS is also supported by the National Research Council (NRC, 2000, p. 29). The first stage of the 5-E lesson is to "Engage" the learner. The teacher sets the stage for learning. The students' attention and focus is grabbed through a variety of attention getters including the use of demonstrations, activating prior knowledge, peaking interest, and activating curiosity. During this stage the teacher can take note of misconceptions stated by the students.

The "Exploration" stage is when students are raising questions and developing hypothesis to test. The students collect evidence and data, record observations, and work in cooperative groups. This stage allows students to experience hands-on learning and "build on a common experience as the students carry out their investigations"

(Llewellyn, 2005, pp. 47-48). The students think freely within the limits of the activity.

The following stage of the 5-E inquiry lesson is "Explanation." The teacher facilitates data and evidence processing techniques using the information gained from the Exploration. The students explain possible solutions and listen critically to each other. The learner formulates the explanations from the evidence. In an open or full inquiry situation the students would be doing all of the explanation. In a guided inquiry the teacher may be giving an explanation after gaining an understanding of student explanations of their exploration findings. This may be the one time that direct instruction by the teacher is used during inquiry.

During the "Elaboration" or "Extension" stage when the teacher helps to "reinforce the concept by extending and applying the evidence to new and real-world situations outside the classroom" (Llewellyn, 2005, pp. 47-48). This stage facilitates the application of correct generalizations in new situations by the students. The teacher can provide follow-up, student-initiated inquiries and expand upon a now teacher-initiated inquiry.

The final stage is the "Evaluation" stage in which the students summarize the variables of the lesson studied. The teacher could pose higher-level thinking questions about their work. The teacher can provide open-ended assessment of the learning which may include monitoring charts or checklists, portfolios or student self-evaluations. The learner communicates and justifies their explanations.

In 1979, Davis examined the effects on student science achievement between two approaches of science instruction, expository text approach and guided inquiry. He studied an expository-text approach where students received direct presentation of information and concepts from the text. In the guided inquiry-discovery approach the students were guided by the material and the teacher. They were engaged in investigations involving inquiry processes structured to develop information and concepts. This study found that the "guided inquiry-discovery approach was significantly more effective then the expository-text approach in achievement of knowledge and information of content contained in the science units" (Helgeson, 1994, p. 261). Also achievement in understanding science inquiry and processes was slightly but not significantly higher in the guided inquiry-discovery group. The students that received the guided inquiry-discovery approach expressed a more positive attitude then those in the expository group.

In a comparison of didactic methods and guided discovery by Thomas in 1968 one can analyze the effects of the varying methodologies on "understanding scientific enterprise, understanding of scientists, understanding of methods and aims of science, achievement of factual-conceptual understanding, use of critical thinking skills, and use of problem-solving skills" (Helgeson, 1994, p. 261). The results showed that for the acquisition of inquiry skills, critical thinking skills, and problem solving skills the high ability groups showed guided discovery to be better then for low ability groups. For the middle students neither method seemed to be superior. The didactic method showed improved results in achievement for the low ability groups.

After a review of many inquiry-based studies Helgeson (1994) concluded that "The most effective approach to teaching science appears to integrate science process skills and science content over several weeks using hands-on, inquiry activities concentrating on specific problem-solving skills." He also claims that, most of the time, inquiry-oriented curricula resulted in improved achievement in science.

A study conducted at the University of Wisconsin indicated that after three years of exposure to kit based inquiry at the elementary level the number of students scoring at "proficient" or "advanced" on the state science achievement test increased form 55% to 80% (Johnson, 2002). In a second study, the Einstein Project's Cornerstone Study, students were taught with inquiry-based method and then compared to five other control schools that were not using inquiry-based methods. The results of the study showed that student in an inquiry-based environment can recall and also perform science better then non-inquiry taught students. The Einstein (inquiry taught) students increased 4% from pre to post test, which was statistically significant. The non-Einstein students increased 1.7% which was not statistically significant. The GOALS assessment that requires open-ended responses showed that the "Einstein students average 18 points more then non-Einstein students in the subject of applying science concepts and making scientific conclusions." These students also performed better on investigation, classification, arranging, drawing and labeling, describing, and explaining a scientific phenomenon (Einstein Project, 2005).

According to the National Research Council the research regarding inquiry in teaching and learning focuses on specific science programs. "Studies of inquiry-oriented curriculum programs demonstrated significant positive effects on various quantitative measures, including cognitive achievement, process skills, and attitudes toward science" (NRC, 2000). The National Science Teachers Association supports the use of scientific inquiry as a teaching approach. The NSTA position statement on scientific inquiry states that teachers should

> plan an inquiry-based science program for their students. Implement approaches to teaching science that cause students to question and explore and to use those experiences to raise questions about their natural world and guide learning using inquiry by selecting teaching strategies that nurture and assess student' developing understandings and abilities. (NSTA, 2004)

The leading organizations of science education in the United States support the use of inquiry-based instruction for science teaching. The research about how students learn plays an important role in the use of inquiry to teach students of science.

Conclusion

The benefits of direct instruction to clarify the content are undeniable. The research for inquiry-based instruction as it relates to how people learn is unquestionable. The problems associated with inquiry lie in how it is implemented in the classroom and the misconception that discovery learning and inquiry are the same. Direct instruction and inquiry can both be used in the science classroom. The 5-E model presented by the BSCS does not eliminate direct instruction from the classroom, instead direct instruction is incorporated into the inquiry lesson plan allowing the students to explore the content being taught followed by an explanation by the students and the teacher. There is a continuum of inquiry instruction from an open inquiry to a more teacher directed type of inquiry.

Science education in the United States has evolved since the conception of the common school. Educators must learn from the successes and failures of reforms of the past and invest in methodologies that support how students' best learn rigorous content knowledge that can be applied in students' lives, now and in their future. The constructivist approach does not mean that the students explore what they want at their own pace. The BSCS 5-E inquiry approach, guided by the teacher, results in the best of both approaches, direct instruction and guided inquiry, for teaching science education.

CHAPTER THREE

THE TRANSFORMATION OF A TRADITIONAL SCIENCE CLASSROOM

The extremes in methodology are illustrated through the use of discovery learning or direct instruction only. Neither method is effective in all situations. Discovery learning without teacher guidance has been looked down upon because the students may not always learn the content that was intended. Direct instruction is mostly centered on the teacher, not the student, and does not fit with the current research-based knowledge of how people learn science (Bransford, Brown, & Cocking, 2000). Direct instruction often prevails in the classroom over inquiry because of the misconception of inquiry as discovery learning. Also, many state standards require that students have a strong factual knowledge base only. Some research about direct instruction reveals that "data and facts can be taught more efficiently" (Tweed, 2004).

In my own classroom I have struggled with implementing inquiry-based lessons. I was taught with the direct instruction methodology and cookbook lab activities in high school and in college. My teaching credential science methods class in 2001-2002 from University of California, Riverside did promote the use of inquiry. I was not exposed to any other way of teaching science besides didactic methods. I was taught about "hands-on" activities to do in the classroom but not about allowing the students to explore topics as described in an inquiry model. "Hands-on" science experiences have been praised as a way to increase student learning in science.

> Hands-on experiences by themselves are insufficient for coming to an understanding for natural phenomenon. Students need to be mentally engaged with the information, not just physically engaged. In the typical cookbook type laboratory experience the students do not engage their cognitive abilities because the students do not raise questions, investigate procedures to answer questions, figure out what date a relevant, acknowledge what the data means, or decide how the knowledge should be communicated to others. (Clough, 2002)

A typical day in my classroom before implementing the idea of inquiry was: a lecture regarding the topic, a step-by-step lab about the topic, a follow-up worksheet, and for homework, questions out of the textbook. The students knew exactly what they needed to memorize, performed reasonably well on the multiple-choice tests and as a new teacher I was able to maintain good classroom management. I soon realized that when I engaged students in conversation about the topics they did not understand the topics although they could regurgitate facts. Their lab reports often had gross errors which they would not recognize because they did not care about, understand, or think about the data. On a lab that the students did requiring them to weigh an egg, I had many students that made an error and described the egg as weighing over 1,000 grams. When asked if they found anything strange about the data they did not recognize this error. Often the free response essay questions on assessments were left blank or filled in with one or two word responses. The students did not truly understand what they were learning. The observations that my students did not understand the material as well as my new knowledge gained through my science education masters program prompted me to make a change in my teaching.

When using the direct instruction model the lab activity occurs after a lecture explaining the concept. The lab activity is performed before any explanation about the topic during an inquiry lesson plan. The following lesson is an example of using direct instruction to teach evolution by means of natural selection. This lesson plan was used in my classroom before I learned about using inquiry.

1. Students arrived to class and answered a review question regarding the information from the day before. It did not pertain to the new information that was to be taught.
2. I would then have the students copy the notes from an overhead, while I talked about the concept of natural selection. Specifically I would describe how non-random mating occurs. Females choose males with the "best" traits; therefore they are more likely to have offspring which causes a shift toward favorable traits in the gene pool. I then asked factual questions about the information while they copied the information from an overhead projector. My notes regarding the topic were gathered from the textbook.
3. I then passed out a worksheet about the textbook information. The students used their notes and textbook to answer the questions.
4. Students performed a lab activity about natural selection. During this activity the students worked in laboratory groups. I gave the students

step-by-step instructions of how to perform the activity. The lab activity I have used is titled Predicting Allele Frequency. The students followed the lab procedure and filled in the data tables. The alleles were represented by brown beans (B) and white beans (b). The beans were held in a cup with an initial population of 50% allele frequency for both of the traits, 100 white beans and 100 brown beans. The students performed a random mating creating 50 offspring by choosing two beans from the cup. They then calculated the allele frequency of the B allele and the b allele in the offspring gene pool. These allele frequencies are usually 50% for each trait just as in the parental generation. They then performed a non-random mating as they removed half of the white beans from the population due to the fact that bb is not a preferential mate choice. After they created the offspring hopefully they noticed that the number of b alleles decreased in the next generation. Most students thought that the lab was about beans not about alleles and the changing of genes over time. It was very difficult for most students to see the connection to what they previously learned about non-random mating in the lecture and the activity they performed.

5. The students would then have a series of six questions out of the textbook for a homework assignment. At the end of the evolution unit students had a multiple choice exam about evolution.

This lesson did not engage the students into the topic, connect to the information their prior knowledge or create understanding about evolution. The NRC provides a model for the variations that can be used during an inquiry lesson in *Inquiry in the National Science Standards* (2000). The table below represents the traits of inquiry within the classroom and the variations that can be seen in an inquiry lesson. This table describes "variations in the amount of structure, guidance, and coaching the teacher provided for students engaged in inquiry" (NRC, 2000, p. 28).

Table 2. Essential Features of Classroom Inquiry and Their Variations

More---------Amount of learner self-direction---------Less
Less---Amount of direction from teacher or material---More

1. Learner engages in scientifically oriented questions.	Learner poses question.	Learner selects among questions, poses new questions.	Learner sharpens or clarifies question provide by teacher, materials, or other sources.	Learner engages in question provided by teacher materials, or other sources.
2. Learner gives priority to evidence in responding to questions.	Learner determines what constitutes evidence and collects it.	Learner directed to collect data.	Learner given data and asked to analyze.	Learned given data and told how to analyze.
3. Learner formulates explanation from evidence.	Learner formulates explanation after summarizing evidence	Learner guided in process of formulating explanations from evidence.	Learner given possible ways to use evidence to formulate explanation.	Learner provided with evidence.
4. Learner connects explanations to scientific knowledge.	Learner independently examines other resources and forms the links to explanations.	Learner directed toward areas and sources of scientific knowledge.	Learner given possible connection.	
5. Learner communicates and justifies explanations	Learner forms reasonable and logical argument to communicate explanations.	Learner coached in development of communication	Learner provided broad guidelines to sharpen communication	Learner given steps and procedures for communication

(NRC, 2000, 29)

This continuum ranges from more to less amount of learner self direction and less to more teacher direction as one moves across the table from left to right. This spectrum of inquiry helped me to transform my classroom. I realized that inquiry is not only what is found on the left side of the chart describing open inquiry. I started by altering my lesson plans slightly to the model shown on the right side of the chart, which describes a guided inquiry approach. It is important to begin with small changes. It would be too difficult for the teacher to suddenly expect the students to perform an open-inquiry during the first exploration of a topic. It is a process for students to learn how to do inquiry activities as well as for the teacher. If students are given an open-inquiry and had never done this type of activity they may give up because of the thought that is required. In my own experience I have encountered students that were not comfortable with their thinking. They asked many questions and expected me, the teacher to give them all of the correct answers as I had done using the previous model. Many students initially became frustrated when I would instead ask them another probing question when they asked me a question.

Obstacles to Transforming the Science Classroom

Upon learning about inquiry-based instruction through my science education masters program, I was confronted with the challenge of transforming my classroom into a more inquiry-oriented classroom. There are many obstacles when implementing inquiry into the science classroom as described by Llewellyn (2005, pp. 51-53) in *Teaching High School Science through Inquiry*. One of the obstacles facing teachers is being familiar with pedagogy. "Most science teachers are well equipped in providing hands-on and problem-solving activities to students, but a lack of a philosophical foundation in learning theory prevails." (Llewellyn, 2005, p. 51) High-stakes multiple-choice assessments do "not accurately assess achievement of all goals of a constructivist teacher" (Llewellyn, 2005, p. 51). The constructivist teacher, as described in chapter two, believes that students learn best when they create their own knowledge through inquiry. The pressure of "covering" the curriculum and standards dares constructivist teachers to deal with the standards that are taught while teaching the topics in detail and with student understanding. The daily schedule of a 45 minute class in a typical school does not provide the amount of time necessary for students to explore a topic within one class period creating yet another challenge for teachers. Most textbooks, except for the BSCS texts, are not inquiry-based.

Another difficulty in using inquiry is that the professional development offered to teachers is often "fragmented, one-shot workshops or in-services that center on the transmission of either content knowledge or classroom management skills presented from the speaker to the audience" (Llewellyn, 2005, p. 52). With these issues in mind science teachers need to be able to adjust their current daily activities gradually to achieve the goal of creating scientifically literate students.

The research regarding how students learn science and the realization that my purpose is to create scientifically literate students urged me to make this change despite the challenges. The BSCS model for inquiry changes the cookbook lab experience into an opportunity for students to think about the concepts instead of merely completing a procedure. I have been able to use the traditional lab activities and change them to fit into the 5-E lesson format.

Llewellyn (2000, p. 63) describes that the transition for teachers to inquiry occurs in four stages "starting with the traditional approach, next exploring inquiry, followed by transitioning to inquiry, and finally practicing inquiry." When using inquiry the role of the teacher changes. During this type of lesson the teachers "pay more attention to student questions and create opportunities for them to collect evidence and use it as a basis for explanations" (NRC, 2000). Teachers can begin the first step into inquiry by making small changes to move from direct instruction to a mostly teacher guided traditional lesson.

The Traditional Approach

The traditional approach is also known as a demonstration of the concept. The teacher poses the question, plans the procedure, and formulates the results. An exemplar of this type of lesson in my own classroom was a demonstration for my students about the role of enzymes to catalyze reactions. Using a demonstration I would ask the question to be answered. What affect do enzymes have on chemical reactions? What conditions affects the rate of a reaction when using an enzyme? I then proceeded into the lesson by describing the materials to be used and the procedure. I then performed the demonstration, provided the students with the data and described to the students the connections between the data and the scientific concepts of enzyme activity. The difference between this approach and direct instruction is that the exploration about the material by the teacher occurs for the students before the explanation of the concept. This change can be easily implemented by reorganized the daily lesson plan. Even though a demonstration is not inquiry it can be used as a beginning point for students to ask further questions about the concepts.

Exploring Inquiry

When I began the next step to implementing inquiry I explored inquiry by posing a question and planning the procedure but the students formulated the results. Llewellyn (2005) described this process as an activity. "Activities can become a means of inviting inquiry and can be used to spring-board into inquiry when like discrepant events, they provide an opportunity for students to make observations or discoveries that are unexpected or unpredicted" (Llewellyn, 2005, p. 68). The question about enzyme activity can be answered by the students, through an activity that is done in small groups of students. The teacher gives the students the question they are to investigate but instead of the teacher performing the procedure, the students follow the procedure outlined by the teacher. They collect data and come to conclusions based upon the evidence they have collected. To activate student thinking during an activity, making this type of lesson an inquiry, the teacher can provide opportunities for students to ask more questions about the concept. They can then decide how to investigate new questions that were raised. Although demonstrations and activities are not inquiry they are a good starting place to move into inquiry.

Teacher-Guided Inquiry

The next step into inquiry for the teacher is to create a teacher-initiated inquiry. The teacher poses the question while the students plan the procedure and formulates the results. This is sometimes also called guided inquiry. This can be a good introduction to inquiry or when the students are having difficulty creating their own questions. "The highest level of inquiry occurs when students raise and initiate their own questions" (Llewellyn, 2005, p. 70). Using a teacher-guided inquiry for the studying enzyme activity the teacher may pose the question, what conditions affect an enzyme? The students would have materials available to them such as liver, potato, carrots, hydrogen peroxide, weak acid, weak base, hot water, and cold water. Using these materials the students create their own procedure to answer the question that was created by the teacher. They would make predictions about what will happen when using the enzyme under different conditions. At the conclusion of the procedure the students would formulate conclusions based on their results.

Student-Directed Inquiry

Student-initiated inquiry begins with the students posing the question, planning the procedure, and formulating the results. The students have an active role throughout during a student-initiated inquiry and a passive role during a demonstration "In a student-initiated inquiry, they teacher could access prior knowledge and uncover misconceptions by asking students to share what they already know..." In this investigation the students would brainstorm about possible causes of enzyme activity rates. The students would create their own questions about the topic and then apply a procedure they create to answer their own question. During the explanation stage of the lesson the students come together as a class and discuss their group results. When analyzing the results of the class the students will make connections to the information about the concept found from outside resources.

Conclusion

The traditional direct instruction method for teaching science is not supported by the research regarding how students learn science. A look into my classroom before implementing inquiry displays the traditional direct instruction lesson plan. Students were not engaged with the material and did not develop a conceptual understanding of the knowledge. There are many obstacles facing science educators to transform the science classroom from the traditional methodology to direct instruction. Llewellyn (2005) described four stages of implementing inquiry into the class. Recognition of these obstacles allows science teachers to overcome the challenges that are faced. How does a science educator make small steps to move from the teacher-centered to more student-centered classroom? The continuum chart shown above is a tool that can be used to begin the transition from a completely direct instruction based classroom to an inquiry-based classroom, through experience, one step at a time.

CHAPTER FOUR

IMPLEMENTATION OF INQUIRY

My initial reaction to using inquiry-based lessons in my classroom was one of improbability. There were so many obstacles to changing my classroom. Time for lesson planning and implementation of inquiry was the first challenge. To overcome these obstacles I decided to make small changes to gradually ease into this new style that benefits student achievement in science. If one were to suddenly change from the traditional way of teaching as described in chapter three to full inquiry most often it would probably be a failure due to the lack of experience by the teacher and students with this methodology. Upon my first introduction to inquiry I decided that I would do a full inquiry lesson. The students did not want to participate in creating their own questions. They were not accustomed to this methodology and I did not possess the skills to facilitate their learning toward the objective.

I challenge teachers to make small changes in their classrooms to create an inquiry-based classroom over time as I have done in my own classroom. Using the continuum chart provided by the NRC (2000) I will demonstrate variations that can be used for the same objective that was described in the direct instruction lesson from chapter three. The lessons range from fully student-guided inquiry to teacher-guided inquiry. One could place their own lessons into this chart to demonstrate how to move from the mostly-teacher guided column to the student-directed column. This chart was adapted from figure in chapter three. The original chart was provided by the National Research Council (2000, p. 29).

Table 3. Variations of An Evolution Lesson Into The Stages of Implementing Inquiry

	Student-guided	More student then teacher input	Both teacher and student input	Mostly Teacher-guided
1. Learner engages in scientifically oriented questions.	Students brainstorm questions to investigate the causes of evolution as it relates to non-random mating. They then choose one of the questions to investigate.	The teacher gives the students a list of questions about evolution as it relates to non-random mating and the students choose a question to investigate.	The teacher gives a prompt for the students to create a question about evolution and how it relates to non-random mating.	Students are given a question to investigate about evolution. How does non-random mating affect allele frequency in a population? The question is provided by the teacher.
2. Learner gives priority to evidence in responding to questions.	Students decide how they are going to collect data to answer the question they have created with the materials provided. They have to create their own data tables to display the information.	Students collect the data from an investigation that is guided by the teacher based upon their question. The students then create their own data tables to display the information about non-random mating as it relates to evolution.	The students create data tables to analyze the data given by the teacher about the allele frequencies in the parental and offspring generations.	The teacher provides data to the students regarding the number of alleles found in the parental and offspring generations. The students are to analyze the information per the teachers' instruction on how to create a data table.
3. Learner formulates explanation from evidence.	The students formulate an explanation about how non-random mating affects evolution after summarizing evidence that was collected.	The students are guided in the process of formulating explanations from the evidence they collected about non-random mating.	The students are given possible ways to use the evidence to formulate explanations about causes of evolution.	The teacher explains the meaning of the data that the students were given about how non-random mating causes evolution.

	Student-guided	More student then teacher input	Both teacher and student input	Mostly Teacher-guided
4. Learner connects explanations to scientific knowledge.	The students examine other resources for the connections to explanations.	Learner directed toward areas and sources of scientific knowledge so they can make the connection between the data collected and evolution.	Learner given possible connection between non-random mating and evolution.	The teacher creates the connection for students to the scientific content knowledge about evolution.
5. Learner communicates and justifies explanations.	The students form reasonable and logical arguments to communicate explanations to the rest of the class. They then reflect on their own learning of the topic through journal writing about the connection between non-random mating and evolution.	The students are coached in their development of communication of the results. The students decide the best way to communicate their results.	The students are provided broad guidelines to sharpen communication of their results. They are given requirements for their presentations.	The students are then given the steps and procedures for communicating of their results to their peers.

Using the knowledge that inquiry-based lessons are found on a continuum I felt comforted that even small changes within my lessons can make a difference. The movement across the columns required small changes by the teacher. As I have progressed through the school year I have traveled across the continuum developing my own skills with inquiry and building the inquiry skills of my students. Teachers need to feel at ease with inquiry and making the students think about the subject matter otherwise the students will sense the teacher's discomfort and disrupt the learning environment. "It is normal for teachers to wait until they grow accustomed to their classes before starting a full-inquiry-based unit. This is especially true for teachers who have students coming to them without prior experience in inquiry learning" (Llewellyn, 2005, p. 72). If the full inquiry lesson does not go well due to a teacher's lack of experience with the methodology they may not attempt an inquiry-based lesson again.

Using The Biological Sciences Curriculum Study 5-E Model of Inquiry

The implementation of the 5-E inquiry teaching model appeared to be an overwhelming task. It was new territory. Using small changes I have transformed my classroom from the didactic, teacher-centered classroom to one which fosters students' questions and engages the learners with the subject matter. The following lesson teaches the same concepts as the lesson described in chapter three but it follows the 5-E model developed by the BSCS. The student-directed column of the inquiry continuum could contain the stages of this lesson.

Engage: The teacher poses a question about evolution and natural selection to activate prior knowledge. An example question may be: How did the giraffe change from having a short neck, as displayed in the fossil record, to the long neck of the modern giraffe? This activates the students thinking about how species change over time.

Exploration: The students will explore the concept of natural selection caused by non-random mating as they analyze a change in allele frequency. Students are asked to design a procedure to find out the allele frequency and genotype frequency of 50 offspring when they have a parental generation that is composed of 50% dominant alleles and 50% recessive alleles. Random mating is occurring in the initial population. The gene pool is given to them and beans represent the alleles. Students are to make predictions about the allele frequency in the offspring's generation using random mating. They need to create their own data tables to display the results. The students will then be asked to explore the issue of non-random mating and how mate choice affects allele frequency. What if the individuals that are bb are undesirable to females? They are to design another procedure to demonstrate the process of non-random mating using the beans as alleles. They again create their own data tables and make predictions about the results.

Explain: The groups of students present their predictions and procedures and what actually happened during the activity. They would describe why they did or did not have the correct prediction and will defend their procedure to explain the changing of alleles during non-random mating. The teacher will prompt the students to relate this to Darwin's theory of evolution. If desirable traits are not passed on at a higher rate then other traits, does evolution occur?

Elaborate: The teacher then asks the students to describe how bacteria evolve antibiotic resistance. If the bacteria does not become resistant to the antibiotic what happens to the bacteria? The students would be applying their new knowledge about allele frequency as it relates to natural selection to a new situation. The teacher would ask probing questions about how the resistant bacteria came into existence. Also, why are the most antibiotic resistant bacteria found in hospitals? They would then be asked to describe this issue using the terminology about natural selection used in class to write about this issue individually for homework.

Evaluate: The assessment would occur as the teacher listens to the students responds. Based on the problem of antibiotic resistance the teacher can conclude if the students reached their objective. Also the students can be presented with the objectives and asked to write about level of accomplishment toward the goal. This meta-cognitive strategy is often used during inquiry for students to assess their own learning.

The basic lab activity using inquiry and direct instruction is the same. The difference is that in the 5-E model the students are asked to think about the information and to predict what will happen. They then performed the activity to see if their predictions matched with their results. They knew nothing of natural selection before they performed the activity but after the activity the students would be able to describe the process of evolution by natural selection in their own words. The students that were taught using the direct instruction method would often not see the connection between the lecture they received and the activity that they performed. Their minds were not activated or engaged as they followed a step-by-step procedure. One of the difficulties that teachers have is, moving directly from the traditional didactic methods to inquiry. It is important for science teachers to understand that there is a spectrum of inquiry lessons that range from open inquiry to guided inquiry.

Role of Questioning in Inquiry

When implementing inquiry the teacher must develop good questioning skills. In an inquiry-based classroom the role of questioning plays a pivotal role in student achievement. Improved questioning skills are an aspect of inquiry that can be utilized by the teacher, which does not require any preparatory time. I began using inquiry by asking the students' questions during laboratory activities that required them to think abut the material. I realized that often students ask questions that they already have the knowledge to answer. Instead of answering students questions I now ask them another question back to activate thinking by the student. For example when the students were performing a fetal pig dissection students would often ask where the stomach was located. I would reply with a question by to the students asking what the stomach is connected to in the body and what the stomach's purpose is. They would then discuss how the purpose and orientation of the stomach as compared to other parts in the pig give clues to its location. Before learning about inquiry I would have simply showed them where the stomach was and more than likely the students would forget the information as quickly as it was given. When the students have to use background knowledge to answer a new question they will hold onto this knowledge because it is connected to a previously held idea. They are reaching a higher level of thinking when they are questioned in this way.

Teachers must not give the students the answers to all of their questions. "During high school, students tend to become more passive and are more accustomed to occasionally providing token answers to questions posed by the teacher" (Llewellyn, 2005). This passive attitude hinders inquiry-based instruction, therefore the teacher has to move slowly with these students toward student directed learning. The students often want to know the "right" answer and do not care if they understand the concept. Douglas Llewellyn (2005) offers tips to teachers that are trying to create an inquiry-based classroom. Science teachers must avoid using "chorus" or group response questions. With this technique the teacher does not know if the entire class supports the answer or if the loudest students only support the answer. A tip that has been helpful in my own classroom is to not repeat student responses. Often the teacher repeats the answer so that the other students can hear the response that was given. This created an atmosphere of students that do not listen to each other; they only listen to the teacher's ideas. When students are forced to listen to each other when the teacher does not repeat the answer, the students pay more attention and often begin a dialogue among their classmates about the concept.

The teacher should ask follow-up questions that probe for student understanding. Often they can provide the definition of a term but the real learning happens when the teacher asks more questions about the material. Also an inquiry teacher needs to know when it is or is not appropriate to answer student questions. The teacher needs to determine if the students have enough background knowledge to find the answer for themselves. If they do not have enough information it is often better to provide the answer to the student. However, if the teacher feels that the student could answer their own question, then the teacher should provide the students with prompts to help them to think about the question for themselves. In my own experience I have found that often when I repeat the question back to them or rephrase the questions slightly, they come up the correct response.

Sometimes when students ask questions I simply say that I do not know the answer. I then persuade the students to develop a plan regarding how they will find out. The teacher is no longer the giver of all subject area knowledge, instead the teacher is a facilitator for the student' learning. It seems to me that students are often lazy in their thinking. If the teacher is willing to give them the answer then why should the teacher expect them to answer their own questions? When the teacher answers all of the students' questions they bypass the acquisition of knowledge. This is a simple change that a science teacher can make when interacting with students. It is difficult to overcome the urge to disseminate the information and allow the students the time to process and explore the concepts.

In my own classroom I have seen the benefits of these inquiry-based methods. Comparing the achievement of my students last year and this year, my current students are receiving higher grades, higher test scores, and acquiring a better understanding of science. There are many variables besides my change in methodology that should also be considered, such as a difference in student aptitude when making this comparison. This year I failed a total of six students out of 72 possible students while last year in the first semester I failed approximately twenty students out of a possible 96 students. Also, the average score my students last year received on the common midterm was a 56% and my current students scored an average of 64% on the same common midterm. These results could be attributed to the change in my philosophy and classroom practices.

Conclusion

Little changes over time can build up to a transformation of the science classroom that activates student learning and interest in the topics being addressed. Beginning with the reorganization of current lesson plans teachers will begin to see a change in the atmosphere of their classroom. As teachers and students become more comfortable with inquiry the teacher moves the lesson from teacher directed to student directed. The teacher needs to develop skills in questioning that leads students into the topic to be studying. Allowing the students to struggle with the content while facilitating their progress toward the objective of the lesson with help them acquire the skills necessary to become scientific thinkers.

CHAPTER FIVE

THE FUTURE OF INQUIRY

The evolution of science education began with the launch of Sputnik by the Russians in 1957. Science reforms have developed out of the competition between the United States and other industrialized countries. Most of the reforms were sudden changes which did not allow for the development of adequate teacher training leading in the new programs ultimately leading to their demise even though if implemented properly these programs may have yielded positive results. Research has been conducted into how students learn science, which influences the teaching of science to students. Students' construction of knowledge through their experiences and connection to prior knowledge increases their understanding of the content, which supports inquiry based instructional methods.

Direct instruction can be useful to clarify the content to students after the students have explored the concept through inquiry-based methods. The misconception of inquiry as discovery learning has decreased the popularity of this method within science classrooms. Science educators need to know that direct instruction and inquiry can both be used in the science classroom. The 5-E model presented by the BSCS (Biological Sciences Curriculum Study) does not eliminate direct instruction from the classroom, instead direct instruction is incorporated into the inquiry lesson plan allowing the students to explore the content being taught followed by an explanation by the students and the teacher. Teachers can feel comforted by introducing inquiry into the science classroom through small variations in their daily lessons.

In chapter three I took a look back at my classroom prior to implementing inquiry-based teaching strategies and realized that students were usually not engaged with the science content I was teaching and often did not develop the conceptual understanding of the knowledge that I had expected. There are many obstacles facing science educators to make the transition from the tradition direct instruction to inquiry. Utilizing the stages of inquiry described by Llewellyn (2005) and the continuum of inquiry lessons provided in chapter four allows the science teacher to incrementally implement inquiry strategies.

In chapter four I have outlined how small change in the science classroom can increase student achievement as the science education moves from direct instruction to inquiry. The reorganization of current lesson plans changes the atmosphere of the classroom to one of student engagement and interest in the content. The development of questioning skills plays a pivotal role in increasing student thinking during exploration of a topic. All of the skills used during inquiry by the teacher and the students need to be developed over time. In my experience, an inquiry-based classroom is not created over night. It is a learning process as the teacher progress across the continuum of inquiry and through the stages of implementation.

Teaching science requires a specialized teacher education program that includes the methodologies that have the highest effect on student achievement.

> For students to understand inquiry and use it to learn science, their teachers need to be well-versed in inquiry and inquiry-based methods. Yet most teachers have not had opportunities to learn science through inquiry or to conduct scientific inquiries themselves. Nor do any teachers have the understanding and skills they need to use inquiry thoughtfully and appropriately in their classrooms. (NRC, 2000)

In my own experience, I received no training with inquiry-based methods. I was a student teacher for an entire school year and neither of my two master teachers used anything except didactic methods with step-by-step dry lab activities. My only exposure to inquiry was in my science education masters program. According to Anderson and Mitchener (1994) science teacher education in the United States has done an inadequate job of preparing teachers for service; I would agree based upon my own pre-service education.

One of the critical issues in the National Science Education Standards is the preparation of science teachers. I do not feel that my own teacher education program during my credentialing prepared me to meet the standards that are outlined by the NRC. As stated in the national standards "Teachers of science plan an inquiry-based science program for their students." (NRC, 1996, p. 32) These standards are based upon research in how students learn science. Also

> Teachers of science guide and facilitate learning. In doing this, teachers:
>
> - Focus and support inquiries while interacting with students.
> - Orchestrate discourse among students about scientific ideas.

- Challenge students to accept and share responsibility for their own learning.
- Encourage and model the skills of scientific inquiry, as well as curiosity, openness to new ideas and data, and skepticism that characterize science. (NRC, 1996, p. 32)

If the National Education Standards support inquiry, why is it that it is not as supported within all science classrooms? The problem lies in the fact that, as in my own training, teachers are not taught about inquiry properly. Many teachers still hold onto the definition of inquiry as discovery from the 1960's. Due to this misconception many teachers do not even want to learn about inquiry in the classroom. Even though the methods that are currently being utilized are widely known to be ineffective for gaining scientific literacy they persist within science teacher education programs.

Science Teacher Education

"Since its beginning, science teacher education has relied heavily on the academic tradition- a liberal arts model- for educating teachers" (Anderson & Mitchener, 1994, p. 9). For reform in science education to occur, the training of teachers needs to be transformed to incorporate how to teach specific science courses through inquiry based methods. College credentialing programs need to be on the cutting edge of educational research in order to inform teachers about how to most effectively teach science.

In my vision of science educators' teaching programs, science teachers would gain the tools to actually teach science. One would think that this is already occurring. I would argue that many teachers are being taught about teaching in general but the methodologies used are not usually specific for the teachers' specialty content. The exposure to content related teaching strategies varies between colleges and universities. Depending upon the professors and state that the credentialing occurs, teachers receive biased instruction on science teaching. If the professor and state support inquiry then possibly the pre-service teacher would receive an education in this methodology. If the professor and the state do not support inquiry then the pre-service teacher would probably not receive training in this methodology.

> In some cases, methods courses portray the teacher as a content expert and focus on techniques to improve the delivery of content.

> On the other hand, some science methods courses emphasize the teacher as a facilitator of learning and focus on making the learners active participants in the learning process. (Anderson & Mitchener, 1994)

The determining factor for creating an inquiry-based teacher lies in the hands-on training of teachers with students. Master teachers found at schools that support student teachers have varying degrees of expertise in using inquiry. Pre-service teachers usually have no knowledge of how a classroom is run except their own experiences in school. They often look to their master teachers as an expert on how to teach science. When these teachers are not experts in the field of science teaching they can steer pre-service teachers in a direction that is not optimal for student achievement. There is a cycle of misinformation in science teaching that needs to be broken. The only way to break the cycle is to reform science teacher training programs. Current science teachers and science teacher trainers need to be informed about the merits of inquiry for science teaching. They also need to know simple steps, as the ones outlined in chapter four, to transform the classroom.

Further Research

Future research needs to focus on the use of the BSCS model for inquiry and its effect on science achievement when implemented properly. This methodology needs to be compared to direct instruction and discovery learning. This type of study would solidify the connection between the research regarding how students learn through constructing knowledge and inquiry-based teaching methods. It would also help to define the distinction between inquiry and the discovery method by researching the effectiveness of each method. The implementation of inquiry during this study needs to occur with teachers that have the training and background to teach inquiry properly; otherwise the results will not be valid.

The college classrooms need to be transformed as well. Teachers often teach as they have been taught. "Veteran science teachers or scientists who aspire to teach may have a strong but traditional science background" (NRC, 2000, p. 92) and may not be familiar with teaching science through inquiry. The National Research Council (NRC) calls for action at the undergraduate level prompting college faculty members to "raise expectations for pre-college preparation in science, engineering, mathematics, and technology (SME&T),

providing inquiry-based interdisciplinary approaches to teacher and learning" (NRC, 1999). Research needs to continue into the use of inquiry in undergraduate courses to improve the scientific literacy of college students. The increase of students in undergraduate programs provides an opportunity for our society to improve the technological skills of the public. The SME&T have a vision of providing all undergraduates with the opportunity to study science, mathematics, engineering and technology early in their academic careers. The progress of the Committee on Undergraduate Science Education Center for SME&T education toward their visions of transformation need to study the impact of knowledge gained in undergraduate courses on society.

Teachers need to be taught how to take theoretical aspects of how students learn science and implement these practices in real classrooms with real students. Further research needs to be done regarding how teachers need to be taught how to teach in a constructivist manner. "How to teach under real world conditions in such a manner as to foster this kind of learning is not as well understood as learning per se" (Anderson & Mitchener, 1994, p. 36).

Future research also needs to explore the role of STS, or integration of science with issues surrounding technology and society, within an inquiry-based classroom. STS is the involvement of students with issues that are related to their own lives. The use of societal and technology-based issues through inquiry-based authentic situations can provide engagement for students with the science content. The exploration of technological and societal issues gives the students the "so what" to motivate involvement in the science classroom. Using STS "results in students with more sophisticated concept mastery and ability to use process skills. All students improve in terms of creativity skills, attitude toward science, use of science concepts and processes in their daily living and in responsible personal decision-making." (NSTA 1996) These issues are also recognized by the NRC as in The *National Science Education Standards* content standard F, science in personal and social perspectives. This standard states: "As a result of activities in grades 9-12, all students should develop understanding of

- Personal and community health
- Population growth
- Natural Resources
- Environmental Quality
- Natural and human-induced hazards

- Science and technology in local, national, and global challenges." (NRC 1996, 193)

The combination of STS and inquiry in the science classroom needs to be researched to determine the effectiveness these two strategies to increase science achievement.

Conclusion

Inquiry in the science classroom plays a critical role in developing a scientifically literate population of citizens. The implementation of this instructional methodology for science teaching is important to increasing the achievement of science students. The steps of transition from direct instruction to inquiry described in chapter four, can be utilized to improve science education in the United States. The first step to the accomplishment of science education reform is letting the voice of inquiry-based research be heard by science educators and giving science teachers the inquiry tools to transform their science classroom.

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